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ABSTRACT

This study questioned whether children's relative inability to use the two cerebral hemispheres independently contributes to their difficulty with the simultaneous execution of conflicting tasks. Two naming tasks involving the identification of upright and inverted letters were employed; conditions differed according to how the letter pairs were distributed within or between visual fields and whether tasks which required conflicting processing were or were not physically separated. It was predicted that (1) division of inputs between the hemispheres would be advantageous only when one hemisphere received upright letters and when the other hemisphere received inverted letters, and (2) the extent to which the hemispheres independently process information would reach a peak during early adolescence. These hypotheses were confirmed in a sample of 120 children. When conflicting inputs were directed to different hemispheres, older children (12- and 14-year-olds) named more items when the inputs were presented bilaterally than when they were presented unilaterally. Younger children (10-year-olds) displayed no advantage for bilateral presentations regardless of whether conflicting tasks were projected to the same hemisphere or different hemispheres. The fact that 10-year-olds did not benefit from division of conflicting inputs between the hemispheres was interpreted as a symptom of their relative inability to use the hemispheres independently. (Author/RH)

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Developmental Changes in Hemispheric Independence

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Developmental Changes in Hemispheric Independence

Abstract

In this research, we questioned whether children's relative inability to use the two cerebral hemispheres independently contributes toward their difficulty with the simultaneous execution of conflicting tasks. Two naming tasks were simultaneously presented to either one visual field/hemisphere combination (unilateral) or were divided between visual fields/hemispheres (bilateral). We predicted that bilateral presentation would improve performance by insulating these conflicting tasks from mutual interference and that there would be a developmental shift in the size of the advantage for bilateral presentation. This hypothesis was confirmed in a sample of 120 children (n = 40 per group). Older children (12 and 14 year-olds) named more items when they were presented bilaterally, rather than unilaterally, when conflicting inputs were directed to different hemispheres. Younger children (10 year-olds) displayed no advantage for bilateral presentation regardless of whether conflicting tasks were projected to the same hemisphere or different hemispheres. The fact that 10 year-olds did not benefit from division of conflicting inputs between the hemispheres was interpreted as a symptom of their relative inability to use the hemispheres independently.

Developmental Changes in Hemispheric Independence

The neurological mechanisms underlying developmental improvements in parallel processing ability are largely unknown. This is despite the fact that parallel processing ability is recognized as being an important component of cognitive development (Blake, 1980; Wickens, 1974). For example, Pascual-Leone (1970) found that parallel processing capability is correlated with Piagetian stages of cognitive development. Similarly, Klahr and Wallace (1976) have created computer models which vary the amount of material which may be processed in parallel and have been able to simulate performance typical of several Piagetian stages.

While these investigations have been successful in quantifying developmental changes in parallel processing ability, as Siegler (1983) has pointed out, they have not identified the mechanisms by which this ability develops. Any of several mechanisms could be responsible for developmental improvements in the ability to perform parallel processing. One mechanism could be an increase in the number of processing units. This is an unlikely mechanism to account for developmental improvement in processing since no new neurons are added to the human brain after the age of about six months (Kaplan, 1972; Winick, Rosso & Waterlow, 1970). A second mechanism could be an improvement in the performance capability of those resources in place. This improvement in performance could be mediated by either a facilitation or inhibition of communication. It is obvious that facilitation of communication, perhaps by faster or higher fidelity transmission, could streamline processing.

Less obvious is the fact that improvements in parallel processing ability may depend on the restriction of information at one or more stages of processing. Restriction of information at the time of stimulus input allows each receiving center to undertake initial processing of its separate input. Restriction of information during actual stimulus processing protects one center from contamination by processing in a second center. We refer to these kinds of restriction of information flow as "processing independence."

Processing independence may be most critical when dissimilar cognitive processes must be carried out simultaneously. As Kinsbourne has suggested (1981; Kinsbourne & Hicks, 1978), the probability of interference is increased when dissimilar, potentially confusable processes are carried out in well-connected regions of the brain. In contrast, the probability of interference is decreased when processing is carried out in relatively disconnected areas of the brain. We suggest that the two cerebral hemispheres could provide such relatively insulated work stations. Interference between cognitive processes may be reduced when processing of different tasks or portions of tasks is done by different hemispheres. This protection afforded by the use of different hemispheres will be referred to as "hemispheric independence."

One means of probing this phenomenon is to project information directly to different hemispheres. Stimuli may be presented directly to one cerebral hemisphere, through hemiretinal stimulation, provided that fixation is maintained at center and stimuli are presented for less than 200 msec (to preclude lateral eye movements). Thus, by arrangement of the materials in the display, information can be presented to either the left or right hemisphere, or it can be divided between the hemispheres.

It should be noted that division of inputs between the hemispheres might

be advantageous for reasons unrelated to hemispheric independence. For example, there could be an advantage associated with the projection of information to two different hemispheres merely because each hemisphere would thereby receive a lighter processing load.

A series of studies has shown that dividing information between the two hemispheres is not always advantageous. In an initial study (Liederman, Merola and Martinez, in press), subjects were asked to judge whether tachistoscopically presented word pairs were from the same semantic category. Words were presented to either the unilateral/left visual field, unilateral/right visual field, or they were divided so that half of the words were presented to each hemisphere (bilateral presentation). There was no performance advantage, in terms of speed or accuracy during bilateral presentations as compared to the better of the two unilateral presentations (i.e., when all of the words were presented to the left hemisphere). In a second study, the same words were presented in the same visual field conditions but subjects had to decide if the words were physically the same (Liederman, Merola, Martinez & Pollock, 1983). Again, there was no advantage for bilateral as compared to unilateral/right visual field presentations.

A third study used a task which would not require comparison of inputs across the visual fields. Once again, subjects were presented words unilaterally versus bilaterally. Subjects could respond correctly in this experiment simply by naming words presented to either visual field. Although naming of words did not require interhemispheric comparisons, there was no advantage to dividing input between the hemispheres as compared to loading all input upon just one hemisphere. Indeed, there was an advantage for unilateral/right visual field presentations (Liederman, 1984).

After closer analysis of our own experiments, and most of those in the

literature, we realized that when materials have been divided between the hemispheres, the materials projected to one hemisphere required a similar kind of processing as the materials projected to the second hemisphere. Under these circumstances it might be inefficient for the hemispheres to coordinate such parallel activity. It follows that if potentially confusing pieces of information were simultaneously presented to the brain, it might be advantageous if these elements could be prevented from interfering with each other. Therefore, we were led to propose the following hypothesis: When conflicting materials are simultaneously presented, performance will be better when the input is divided between the hemispheres than when all of the materials are projected to a single hemisphere (either the left or the right hemisphere). This advantage will only be seen, however, when each hemisphere receives materials which require only one kind of processing.

The conflicting tasks which we selected were the naming of upright versus inverted letters. We chose letter naming because similar materials could be made to require different processing merely by changing the orientation of their presentation. Identification of inverted letters has been shown to be a different process than identification of upright letters (Childs and Polich, 1979). In the context of our experiment we predicted that division of inputs between the hemispheres would be advantageous only when one hemisphere received upright letters and the other hemisphere received inverted letters.

We also predicted that the extent to which the hemispheres independently process information reaches a peak during early adolescence. The inhibition of unintended motor overflow to contralateral limbs increases sharply with age and reaches its peak by adolescence (Connolly & Stratton, 1968). This increase in inhibition of contralateral motor overflow may signal a general increase in insulation between the two cerebral hemispheres. For example,

Waber and Merola (1984) presented young adolescents with a dichotic listening task during which different words were presented simultaneously to the two ears. The ability of females to inhibit intruding words from the contralateral ear correlated significantly with inhibition of unintended contralateral motor overflow.

There is also reason to believe that cognitive development undergoes a major change during adolesence. For example, the stage of formal operations begins around the time of puberty (Piaget, 1972) and Pascual-Leone (1970) has found that there is an abrupt increase in parallel processing capability which corresponds to the onset of formal operational thinking. One of the few other cognitive changes which has been linked directly to puberty was that reported by Diamond, Carey, and Back (1983). They found that girls at puberty do not encode faces as well as pre- or post-pubescent girls, regardless of age.

A major obstacle to research on puberty has been the expense and logistical difficulty involved in obtaining measures of physiological development, such as medical examination and radiographs of bone growth. This problem was circumvented by using an estimated age of onset of menarche based upon the research of Frisch (1974). Frisch's non-invasive method predicts age of menarche for 9 to 13 year-old females. Height and weight are used to estimate total body water as a percent of body weight which, in turn, is a good index of body composition (i.e., the proportion of fat, bone, and muscle). The logic behind these indices is that when the ratio between fat, water and total body weight reaches a critical value, onset of menarche is triggered. Menarche is thought to commence only when the body has stored sufficient calories in the form of fat to support a full-term pregnancy.

In summary, this study examined one possible basis for improvements, around the time of puberty, in the performance of conflicting simultaneous

tasks. The proposed mechanism by which conflicting processing becomes increasingly protected is an increase in the parallel use of the two hemispheres. These changes in hemispheric independence are hypothesized to be correlated with estimates of the onset of puberty and/or degree of physical maturation.

Method

Subjects

The subjects were children from seven schools in the Worcester (MA) Public School system (see Table 1). These 120 children were from age groups 10, 12, and 14 years. Within each age and gender group (n = 20 each), half of the children were from a high scholastic ability group (Otis-Lennon Achievement test scores above 100) and half were from a low-average ability group (scores 85-100). No children with a history of learning or emotional disabilities were tested. Subjects were excluded from the study if (a) they received handedness questionnaire scores of +15 or less for the right hand or +5 or greater for the left hand (see below); (b) used an inverted handwriting posture; (c) showed superiority for the left hand on the Purdue Pegboard task; or (d) indicated that they had first degree relatives with a left hand preference.

Insert Table 1 about here

Subjects were selected from the above age levels because, according to Tanner (1962), the observable somatic changes of puberty have not commenced in the majority of 10 year-olds (M age = 10.49 years), whereas these changes are apparent in the majority of 14 year-olds (M age = 14.44 years). Children from

high and low ability groups were selected to guarantee representation of a full spectrum of normal cognitive ability within each grade level.

Tasks

Handedness Assessment. A 10-item handedness questionnaire (Oldfield, 1971) was administered. Subjects were given two points for indicating a strong hand preference for a task (i.e., the subject would always use the hand unless forced), one point for indicating a moderate preference, one point for each hand if indifferent as to which hand to use, and zero points if they never used a given hand for a task. In addition, the hand preference (right, left, or ambidextrous) of first degree relatives was recorded to screen for familial sinistrality. Subjects were timed during the Purdue Pegboard task. Order of hand use was counterbalanced across subjects.

Somatic Growth. Subjects' heights and weights were measured using a height chart and Detecto metric scale, respectively.

Maturation Measures. Percent body fat, total body water, lean body weight, fat as percent of body weight, and total body water as a percent of body weight were estimated from height and weight measurements using the formulas derived by Frisch (1974).

Tachistoscopic Task

Design. Two kinds of materials were selected which required two distinctly different and conflicting kinds of processing. The first kind involved identification of letters rotated by 180 degrees around the horizontal axis. We shall refer to these letters as "inverted." The second kind involved identification of upright, non-inverted letters.

On each trial the subject was presented with two pairs of letters to name, and on each trial two of those letters were upright and two of those letters were inverted. Letters within a pair were contiguous, with one letter

directly above the other. In contrast, the two letter pairs were physically separated from one another. Conditions differed according to a) how the letter pairs were distributed within or between the Visual Fields, and b) whether tasks which required conflicting processing were or were not physically separated.

There were four visual field conditions: Two involved presentation of all four letters to one visual field - a unilateral/right visual field condition (RVF) and a unilateral/left visual field condition (LVF) (see Figure 1). The other two visual field conditions consisted of two types of bilateral configurations. In the first condition, the letters were bilaterally distributed on the cards so that pairs of letters were in opposite corners along the same horizontal plane. Letter pairs were separated by the same distance and were positioned at the same visual angle from fixation as they were in the unilateral presentations. The problem with this format was that letters horizontally positioned might facilitate post-exposural scanning. Therefore, a second kind of bilateral configuration was included in the design, so that letters were diagonally rather than horizontally opposed. These two conditions will be referred to as the bilateral/horizontal format and bilateral/diagonal format, respectively (see Figure 1).

The second variable which was manipulated was the physical separation between inverted and upright letters within a display. Conflicting tasks were considered physically separated when the adjacent letters in one pair were both inverted and the adjacent letters in the second pair on the display were both upright. Conflicting tasks were considered unseparated when each letter pair contained one inverted and one upright letter. Within each visual field condition, conflicting tasks were physically separated in half of the stimulus displays (i.e., both letters were inverted in one letter pair and both letters

were upright in the second pair; see Figure 1, top) and conflicting tasks were physically unseparated in half the stimulus displays (i.e., one inverted and upright letter in each pair; see Figure 1, bottom). This variable will be referred to as the physical separation variable (separated vs. unseparated).

Trials during which conflicting tasks were unseparated served as control conditions. For two of the unseparated presentation conditions, all letters were directed to a single visual field/hemisphere (unilateral/LVF and unilateral/RVF), whereas for the bilateral presentation condition, one upright and one inverted letter were presented to each of the visual fields/ hemispheres. Comparison of bilateral and unilateral unseparated trials allowed us to assess whether there was a performance advantage associated with division of the tasks between the hemispheres, even when the materials were presented so that <u>each</u> hemisphere received inputs which required conflicting processing.

Insert Figure 1 about here

<u>Stimulus materials</u>. Eight types of display containing consonant capital letters were used, representing the four visual field conditions and two physical separation conditions. There were four letters on each card, grouped in pairs, with one letter beneath the other.

Letters for the stimulus cards were consonant capital letters in 36 point Helvetica Bold type drawn from the letter pool B, C, D, F, G, J, K, L, Q, R, T, V. They spanned a visual angle of 0.94 degrees. These letters were chosen because they lack symmetry about the horizontal axis and are not easily confused with one another. Vowels were excluded to prevent subjects from forming words or nonsense syllables. Letters were selected randomly without

replacement; on each card two letters were inverted and two letters were upright. A random digit from 1 to 4, printed in Helvetica Regular type was presented at the fixation point of each display. Digits spanned between 0.34 and 0.52 degrees of visual angle depending upon the number.

In all four visual field conditions, letters were positioned at a visual angle of 3 degrees from center. Letters occurred as often at the top as at the bottom corners of an imaginary square. For the bilateral/diagonal format trials, letters were located at the upper left and lower right locations for half of the trials and for the remaining trials letters were located at the lower left and upper right positions.

Apparatus. The visual task employed a Gebrandts two field tachistoscope (visual distance of 53.34 cm), lampdrive and presentation timer.

Procedure. Subjects were told to name each of the 12 letters, once with the letters upright and once with them inverted. They were then shown cards representative of each of the possible visual field arrangements. Subjects were told that numbers and letters would be briefly presented and that the task was to name the center number and as many letters as possible. Sample cards containing only central digits were then presented via the tachistoscope. Subjects viewed a maximum of 20 cards until they correctly named 10 consecutive digits. Subjects were reminded to focus on the fixation dot at the beginning of each trial. Displays were then presented for 40 msec. A card with the 12 letters was kept next to the subjects as a reference.

Each condition was displayed once every eight trials on a random basis. Stimulus sequence was also randomized between subjects. Two blocks of 40 trials were administered. Between blocks, height and weight were measured and the Purdue Pegboard task was completed.

Results

A trial was considered acceptable when the subject correctly identified the central fixation digit. On the average, 94.8% of the 80 trials were acceptable. The dependent measure was the proportion of letters correctly named on acceptable trials. An arcsine transformation was applied to these proportions and a series of repeated measures analyses of variance were computed). The between subjects variables were age (10, 12, 14), gender (male, female), and scholastic ability group (high, low). The within subjects measures were separation of conflicting tasks (separated vs. unseparated) and visual field (bilateral vs. unilateral/RVF vs. unilateral/LVF). The bilateral/horizontal and bilateral/diagonal conditions were treated as one condition since there was no significant difference between them. For each of the analyses reported below, interaction effects were decomposed by means of a Scheffé test, with the alpha level set at .05.

Main Findings

There was a significant interaction between age, visual field, and separation of conflicting tasks ($F(4, 216) = 2.71$, $p < .05$). This interaction was then decomposed into simple main effects within each age level. Means and standard deviations for these 18 cells are provided in Table 2.

Insert Table 2 about here

Within the 14 and 12 year-old samples, there was a significant interaction between visual field and separation of conflicting tasks (14 year-olds: $F(2, 72) = 3.13$, $p < .05$; 12 year-olds: $F(2, 72) = 6.49$, $p < .01$). When conflicting tasks were separated, performance during the bilateral conditions was significantly better than in either of the unilateral conditions (14

year-olds: bilateral vs. unilateral/LVF, $F(1, 36) = 46.09$, $p < .05$; bilateral vs. unilateral/RVF, $F(1, 36) = 17.10$, $p < .05$; 12 year olds: bilateral vs. unilateral/LVF, $F(1, 36) = 54.55$, $p < .05$; bilateral vs. unilateral/RVF, $F(1, 36) = 23.53$, $p < .05$). When conflicting tasks were not separated, there was no advantage for bilateral presentation as compared to performance during the better of the two unilateral conditions (i.e., performance during unilateral/RVF stimulation ($F(1, 36) = 2.45$, $p > .10$).

In the youngest group, i.e., the 10 year-olds, there was no significant interaction between visual field and separation of conflicting tasks ($F(2, 72) = 0.31$, $p > 70$). There was no advantage for bilateral presentation as compared to the better of the two unilateral conditions irrespective of whether conflicting tasks were or were not separated.

A series of analyses was also computed in which performance during bilateral presentation was compared to the average of the two unilateral conditions. In all cases, the pattern of results was not changed by this reduction of the data. For trials during which conflicting tasks were separated, the proportion of letters named across bilateral trials was significantly higher than the proportion of letters named across all unilateral trials. For trials within which conflicting tasks were not separated, there was no overall advantage associated with bilateral as compared to unilateral presentation.

The Hemispheric Independence Index

Conflicting inputs were directed to different hemispheres during only one of the presentation conditions. This was the bilateral condition during which the upright letters were presented to one visual field and the inverted letters were presented to the opposite visual field. During the four unilateral visual field conditions, both upright and inverted letters were

presented to a single visual field/hemisphere. Similarly, during the other bilateral presentations, one upright letter and one inverted letter were each presented to each visual field. The dependent measure for the next set of analyses was an index which represented the difference between the proportion of letters correctly named during the one bilateral condition when conflicting inputs were divided between the hemispheres and the proportion named during the average of all of the other treatment conditions (when conflicting inputs were not separated between the hemispheres).

This index was named the hemispheric independence index, because division of conflicting inputs between the hemispheres should only be beneficial if the two hemispheres operate more independently than regions within a hemisphere. Positive index scores indicated the extent to which presentation of conflicting inputs to separate hemispheres was beneficial. Negative index scores indicated the extent to which presentation of conflicting inputs to separate hemispheres was not beneficial. An analysis of variance with age, gender, and scholastic ability as the between subjects variables indicated a significant effect of age ($F(2, 108) = 8.19$, $p < .001$). Post-hoc analyses confirmed that the hemispheric independence index scores of the 12 and 14 year-olds were higher than those of 10 year-olds. There was also a marginal effect of gender ($F(1, 108) = 2.81$, $p = .09$), with males having higher index scores than females (see Figure 2).

Insert Figure 2 about here

The Proportion of Children Manifesting Strong Hemispheric Independence

The next analyses compared the proportion of children in each age group who were characterized as showing an advantage for the division of conflicting

inputs between the hemispheres. Children who had positive hemispheric Independence Index scores were categorized as "strong" whereas those with negative scores were categorized as "weak" in terms of hemispheric independence. A chi-square test of independence indicated that there was a significant association between age and strong vs. weak hemispheric independence ($\chi^2(2, N = 120) = 11.41$, $p < .01$), with older children showing strong hemispheric independence more often than younger children. As can be seen in Table 3, approximately half of the 10 year-old children were characterized as weak in hemispheric independence; whereas only a fifth of the older children were characterized as weak in independence.

Insert Table 3 about here

Analyses Which Rule Out Competing Explanations for the Phenomenon

There are several possible sources of artifact which can be ruled out in the interpretation of these data. One confound might be that there is a special advantage associated with the bilateral configuration in which upright letters are projected to the "verbal" left hemisphere and inverted letters are projected to the "spatial" right hemisphere. To rule this out, performance during bilateral trials when upright letters were projected to the RVF/left hemisphere and inverted letters were projected to the LVF/right hemisphere was compared to trials when the opposite occurred, i.e., upright letters were projected to the LVF and inverted letters were projected to the RVF. There was no significant difference in performance between these two configurations of the bilateral condition ($F(1, 108) = 0.38$; $p > .50$). This demonstrates that the advantage of the bilateral condition was not skewed by the presence in one of the two configurations, of a unique compatibility between the kind

of materials and the processing specialization of the receiving hemisphere.

Since 10 year-olds lacked the advantage for the bilateral condition when conflicting inputs were presented to separate hemispheres, which was shown by the 12 and 14 year-olds, we next questioned whether these children differed from the older children in terms of cerebral laterality. To test this, an analysis was performed which used the RVF minus LVF difference score as the dependent measure. This difference in performance for materials presented to the two visual fields is a traditional index of the extent to which verbal materials are better processed when presented directly to the left rather than right hemisphere. Results indicated that performance during unilateral/RVF trials was superior to that during unilateral/LVF trials, across age groups, and that the size of this difference in cerebral laterality did not differ significantly between age groups.

The Relationship Among the Hemispheric Independence Index, Maturation Measures, and Overall Performance

The preceding analyses indicated a reliable relationship between age and the hemispheric independence index. We next computed correlations between the hemispheric independence index, several measures of physical maturation in females, and a measure of overall performance. The measures of physical maturation were total body water, total body water as a percent of body weight, lean body weight, body fat, and fat as a percent of body weight, as outlined by Frisch (1974). The measure of overall performance was the proportion of letters named on acceptable trials averaged across conditions. There were no significant correlations between the hemispheric independence index and any measures of physical maturity when correlations were computed across and within ages.

The hemispheric independence index was significantly correlated with the

overall performance measure when correlations were computed across age (r = .374, $p < .001$). This relationship remained significant within the 12 year-old sample (r = .499, $p < .001$), but was only marginally significant within the 14 year-old sample (r = .262, p = .10), and was not significant within the 10 year-old sample.

Secondary Effects

It should be noted that there were other significant effects which were unrelated to this study's central hypothesis. Post hoc analysis of a significant Block X Visual Field X Separation interaction ($F(2, 216) = 3.54$, $p < .05$) revealed that during bilateral, but not unilateral, trials, performance improved with practice when conflicting tasks were physically separated ($F(1, 108) = 20.59$, $p < .001$).

There were two significant between-subject interaction effects. The first was an Ability Group X Age X Gender interaction ($F(2, 108) = 5.27$, $p < .01$). Children with higher Otis-Lennon scores named a higher proportion of letters than children with lower scores, except for 10 year-old males and 14 year-old females. The second effect was a Gender X Visual Field interaction ($F(2,216) = 12.35$, $p < .001$). During the bilateral trials, males named a higher proportion of letters than females.

Discussion

The results of this study are compatible with our first hypothesis that there are developmental changes in the degree to which the conflicting portions of simultaneous tasks are processed separately by the two hemispheres. This was tested by presenting young adolescents with two potentially conflicting tasks, simultaneous identification of inverted versus upright letters. We reasoned that for older children decoding of these

conflicting inputs would be easier if the tasks were projected to two hemispheres, rather than one. This advantage for interhemispheric separation of conflicting tasks was predicted because the degree to which information processing occurs independently in the two hemispheres was expected to increase at puberty. A strong developmental effect was found: 12 and 14 year-old children benefited from the division of conflicting inputs between the hemispheres whereas 10 year-old children did not. These results suggest that as compared to older children, young children may be less able to restrict the activity in one hemisphere from influencing activity in the second hemisphere.

The fact that 10 year-old children did not benefit from the division of conflicting inputs between the hemispheres was probably not a statistical artifact. The proportion of letters correctly named by 10 year-olds was normally distributed, and the variance was not significantly different from that observed in the other two age groups. Similarly, the findings were not due to a general floor effect; the mean proportion of letters correctly named by the 10 year-olds differed by only 8% from that of the 12 year-olds. Nor was the absence of the bilateral advantage in 10 year-olds due to a general difficulty with the bilateral presentations. Their performance during bilateral presentation did not significantly differ from that during the unilateral presentations.

The fact that the 10 year-old group's performance did not excel during the bilateral condition in which conflicting inputs were presented to different hemispheres cannot be attributed to their use of a peculiar attentional strategy. For example, these younger children, when overloaded by the four-letter display, might have chosen the strategy of attending only to the upright letters. If the 10 year-old children ignored the inverted letters, they would no longer be trying to process conflicting tasks. This argument is

invalidated by the fact that the 10 year-old children did not ignore the inverted letters. Ten year-old children named approximately the same proportion of inverted as non-inverted letters (50%), and this proportion of inverted letters did not differ significantly from the proportion named by either the 12 or 14 year-old children.

It is also not likely that 10 year-olds lacked an advantage for the bilateral condition because of the immature way that they scanned the materials post-exposurally. The 12 and 14 year-olds, who are relatively advanced readers, might have found the bilateral (horizontal) displays disproportionately easier to scan than the unilateral (vertical) displays. In contrast, the 10 year-olds might not have benefited from the left-to-right configuration. One problem with a post-exposural scanning explanation is that it would predict an advantage for the bilateral condition in advanced readers, irrespective of whether conflicting tasks were directed to different hemispheres. In addition, if scanning were critical, the bilateral/diagonal displays, which require oblique scanning, should have been less advantageous than the bilateral/horizontal displays. Neither of these results occurred. We modified the experiment with 10 college freshmen so that post-exposural scanning of the displays was prohibited by a mask. The bilateral condition for which conflicting inputs were directed to different hemispheres was still advantageous.

Note that this developmental change in hemispheric independence can not be explained in terms of developmental changes in cerebral dominance. The children within each age group named more letters when they were projected to the left, rather than the right, hemisphere, and the size of this performance asymmetry did not change significantly across ages.

Developmental increases in hemispheric independence could be caused by

changes in the ways that the hemispheres collaborate during information processing. One change might have to do with how well insulated one hemisphere is from the operations of the other hemisphere. As the brain develops, processing which is occurring in one hemisphere may be better shielded from processing which is occurring in the other hemipshere. Selective decreases in interhemispheric interference could be caused by changes in the speed or number of inhibitory signals mediated by the corpus callosum. Such changes in collosal function might be due to completion of myelinization of the corpus callosum (Yakolev & Lecours, 1967), increased selectivity of callosal connections, or increases in the proportion of callosal fibers which synapse upon inhibitory (e.g., gabaminergic) interneurons.

There is another way that hemispheric independence could increase developmentally. This second way has little to do with the amount of inhibition between the hemispheres. It instead relates to the point during problem solving when the hemispheres begin to collaborate. In younger children, a "verbal" task may be more likely to be delegated solely to the specialized hemisphere. In older children, there may be greater flexibility in the way that the same task is performed. For example, preliminary stages of processing might sometimes take place in the hemisphere that received the task, even if that hemisphere was not capable of completing that processing. In this case, hemispheric independence would increase developmentally because each hemisphere could at least begin to process the information which it receives before collaborating with the other hemisphere. At this time, it is not possible to determine the relative importance of changes in hemispheric insulation versus processing flexibility as determinants of the observed developmental increase in hemispheric independence.

Although these data strongly suggest that the degree to which the hemispheres can process independently increases in children between the ages of 10 and 12, they do not suggest that this developmental sequence is linked to the onset of puberty, in general, or menarche, in particular. None of the measures of physical maturity in females were significantly correlated with the hemispheric independence index. Moreover, the size of this index differed only marginally between males and females. Since males are often still pre-pubescent when females are post-pubescent, the absence of a reliable gender difference may suggest that puberty is not the relevant trigger for this developmental change. In addition, only three of the twenty 12 year-old females were characterized as post-menarchal, yet strong hemispheric independence was prevalent in the 12 year-old sample as a whole. Taken together, these data suggest that our second hypothesis was disconfirmed; menarche is not the trigger for the increases in hemispheric independence observed in our study.

It must be emphasized, however, that this study is only preliminary. Frisch's method of estimating age of menarche may not have been adequately precise. The time difference between the actual age of menarche and that estimated by Frisch (1974) was incorrect by at least seven months for approximately 46% of her sample (N = 236), and was incorrect by at least 14 months for approximately 17% of her sample (N = 85).

Moreover, the onset of puberty does not occur at a discrete point in time. Many of the indices of puberty are not correlated with each other, and the onset of puberty in males is complicated to measure or predict. For example, Diamond, et al. (1983) have suggested that girls progress through the stages of puberty at different rates than boys. As Marshall and Tanner (1969, 1970) have shown, the difference between boys and girls in the onset of the

growth spurt is 1.9 years, whereas the difference for the third stage of pubic hair growth is 1.4 years, and the difference for the third stage of breast develcpment/genital development is only 0.7 years.

Our results suggest one possible mechanism by which the parallel processing of conflicting inputs improves developmentally. It is suggested that the degree to which the two hemispheres can process information independently increases markedly during early adolescence. This neuropsychological change provides a decrease in inter-task interference when separate hemispheres are responsible for the conflicting portions of the tasks. Whether these changes are related to either onset of puberty or rate of physical maturation is open to further research.

References

Blake, J. (1980) Parallel processing of same and different form arrays in children and adults. Perceptual and Motor Skills, 50, 1011-1018.

Childs, M.K. and Polich, J.M. (1979) Developmental differences in mental rotation. Journal of Experimental Child Psychology, 27, 339-351.

Connolly, K., & Stratton, P. (1968) Developmental changes in associated movements. Developmental Medicine and Child Neurology, 10, 49-56.

Diamond, R., Carey, S., & Back, K. (1983) Genetic influences on the development of spatial skills during early adolescence. Cognition, 167-185.

Frisch, R. E. (1974) A method of prediction of age of menarche from height and weight at ages 9 through 13 years. Pediatrics, 53, 384-390.

Kaplan, B. (1972) Malnutrition and mental deficiency. Psychological Bulletin, 78, 321-334.

Kinsbourne, M. (1981) Single channel theory. In D. Holding (Ed.), Human skills (pp. 65-89). New York: John Wiley and Sons.

Kinsbourne, M. and Hicks, R.E. (1978) Functional cerebral space: A model for overflow, transfer and interference effects in human performance: A tutorial review. In J. Requin (Ed.), Attention and performance (Vol. 7, pp. 345-362). Hillsdale, N.J.: Lawrence Erlbaum Associates.

Klahr, D., & Wallace, J. (1976) Cognitive development: An information-processing view. Hillsdale, NJ: Lawrence Erlbaum Assoc.

Liederman, J. (1984) Interhemispheric interference during word naming. Manuscript submitted for publication.

Liederman, J., Merola, J., Martinez, S., & Pollack, F. (1983, June) Interhemispheric vs. intrahemispheric processing: The effect of level of

processing. Paper presented at the European Meeting of the International Neuropsychological Society, Lisbon, Portugal.

Liederman, J., Merola, J., & Martinez, S. (in press) The difficulty of interhemispheric integration in response to simultaneous bilateral input. Neuropsychologia.

Marshall, W.A., & Tanner, J. (1969) Variations in the pattern of pubertal change in girls. Archives of Disease in Childhood, 44, 291-303.

Marshall, W.A., & Tanner, J. (1970) Variations in the pattern of pubertal changes in boys. Archives of Disease in Childhood, 45, 13-23.

Oldfield, R. (1971) The assessment and analysis of handedness. Neuropsychologia, 9, 97-113.

Pascual-Leone, J. (1970) A mathematical model for the transition rule in Piaget's developmental stages. Acta Psychologica, 32, 301-345.

Piaget, J. (1972) Intellectual evolution from adolescence to adulthood. Human Development, 15, 1-12.

Siegler, R. (1983) Information processing approaches to development. In P. Mussen (Ed.), Handbook of child psychology: Vol. 1. History, theory, and methods (4th ed., pp.). New York: John Wiley & Sons.

Tanner, J. (1962) Growth at adolescence (2nd ed.). Oxford: Blackwell Scientific Publications.

Waber, D., & Merola, J. (1984) Motor correlates of dichotic listening asymmetries in children. Manuscript submitted for publication.

Wickens, C. (1974) Temporal limits of human information processing: A developmental study. Psychological Bulletin, 81, 739-755.

Winick, M., Russo, P., & Waterlow, J. (1970) Cellular growth of cerebrum, cerebellum, and brain stem in normal and marasmic children. Experimental Neurology, 26, 393-400.

Yakolev, P., & Lecours, A. (1967) The myelinogenetic cycles of regional maturation of the brain. In A. Minkowski (Ed.), Regional development of the brain in early life (pp. -). Oxford: Blackwell Scientific Publications.

Table 1

Subject Sample Size by Subgroups

Gender		Age					
		10		12		14	
		Low Ability	High Ability	Low Ability	High Ability	Low Ability	High Ability
Male	n	10	10	10	10	10	10
Female	n	10	10	10	10	10	10

Table 2

The Effect of Inter- vs. Intra-Hemispheric Separation of Conflicting Tasks Upon the Mean Proportion of Letters Named by Age Group

CONFLICTING TASKS SEPARATED FROM MUTUAL INTERFERENCE:

		Interhemispherically	Intrahemispherically	
		Bilateral	Unilateral/LVF	Unilateral/RVF
Age				
10 years	M	.397	.362	.390
	SD	.1246	.1314	.1485
12 years	M	.527	.434	.466
	SD	.1465	.1267	.1165
14 years	M	.471	.399	.409
	SD	.1273	.1186	.1408

CONFLICTING TASKS NOT SEPARATED FROM MUTUAL INTERFERENCE:

		Interhemispherically	Intrahemispherically	
		Bilateral	Unilateral/LVF	Unilateral/RVF
Age				
10 years	M	.406	.355	.390
	SD	.1221	.1254	.1194
12 years	M	.493	.449	.487
	SD	.1179	.1256	.1221
14 years	M	.454	.405	.436
	SD	.1168	.1183	.1131

Table 3

The Proportion of Children Within Each Age Group With Weak vs. Strong Hemispheric Independence

Age	Hemispheric Independence	
	Weak	Strong
10 years	19 (47.5%)	21 (52.5%)
12 years	9 (22.5%)	31 (77.5%)
14 years	6 (5.0%)	34 (85.0%)

* $p < .01$

Figure Captions

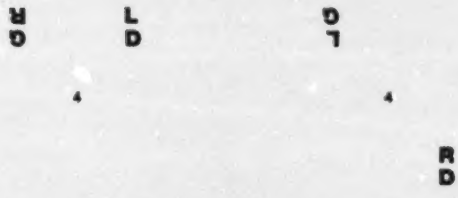
Figure 1. Design of the tachistoscopic letter naming experiment

Figure 2. The effect of age and gender on the hemispheric independence index

Figure 1

Conflicting Tasks Separated From Mutual Interference:

Inter-Hemispherically



Bilateral/ Horizontal

5 stimuli per block

Bilateral/ Diagonal

5 stimuli per block

Intra-Hemispherically

Unilateral/ LVF

5 stimuli per block

Unilateral/ RVF

5 stimuli per block

Conflicting Tasks Not Separated From Mutual Interference:

Inter-Hemispherically

Bilateral/ Horizontal

5 stimuli per block

Bilateral/ Diagonal

5 stimuli per block

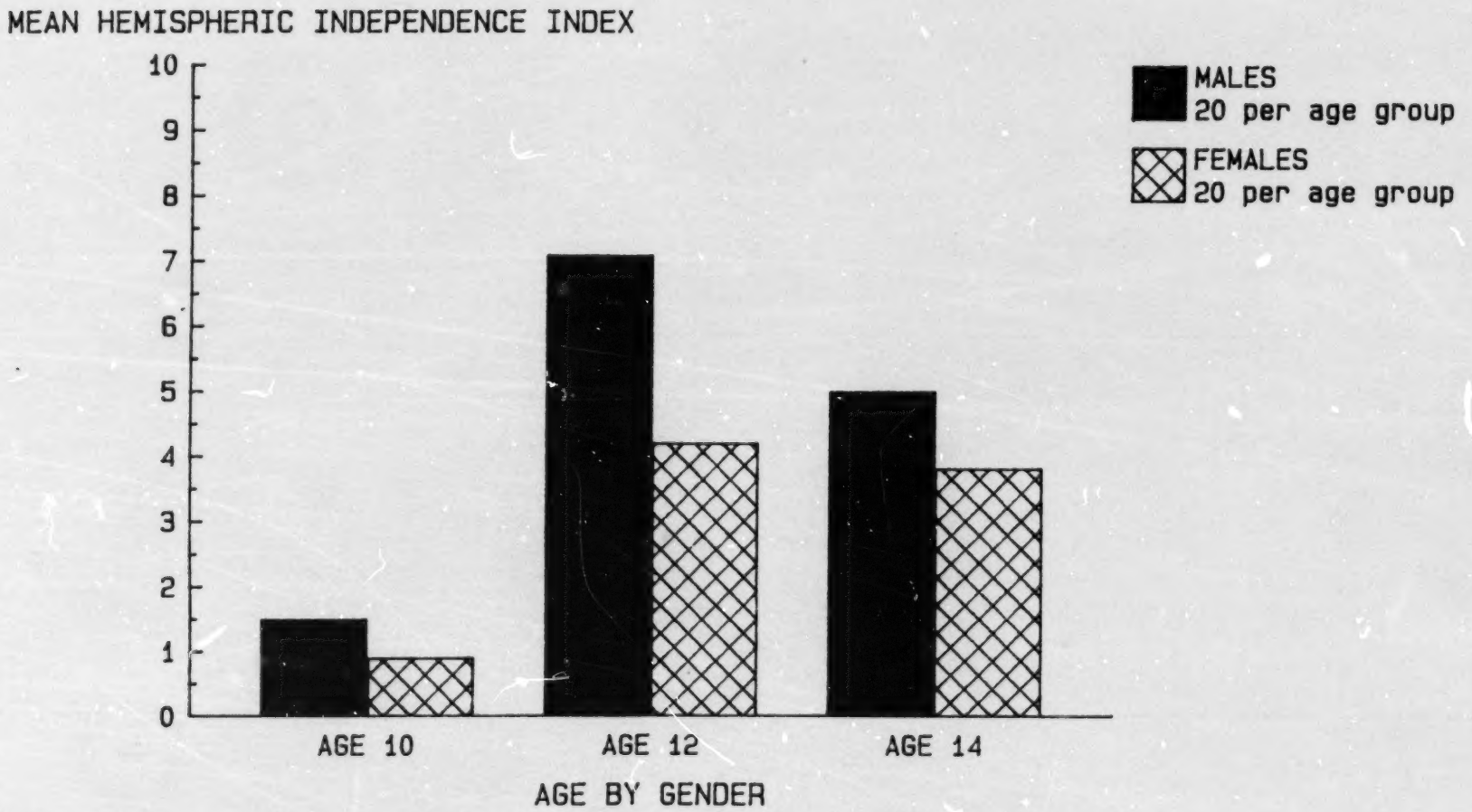
Intra-Hemispherically

Unilateral/ LVF

5 stimuli per block

Unilateral/ RVF

5 stimuli per block



33 Age 10 < Age 12 = Age 14 ($p < .05$)
No gender differences were significant